

Study of charmonium production in asymmetric nuclear collisions by the PHENIX experiment at RHIC

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Quarkonia as a Probe of Deconfined Matter

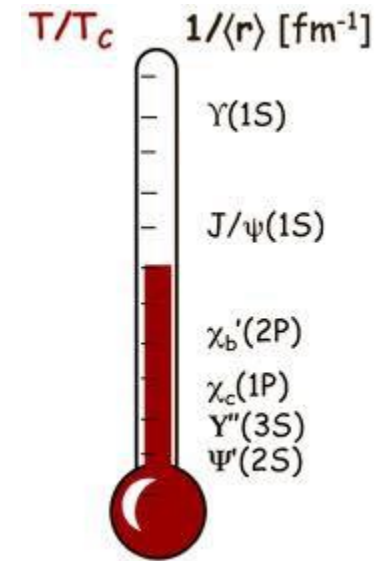
Dissociation of quarkonia by color screening in deconfined matter is predicted to be different for different states. Loosely bound states melt first. Successive suppression of individual states provides a “thermometer” of the QGP.

Excellent tool to probe QGP....

...but only if we know all the references.

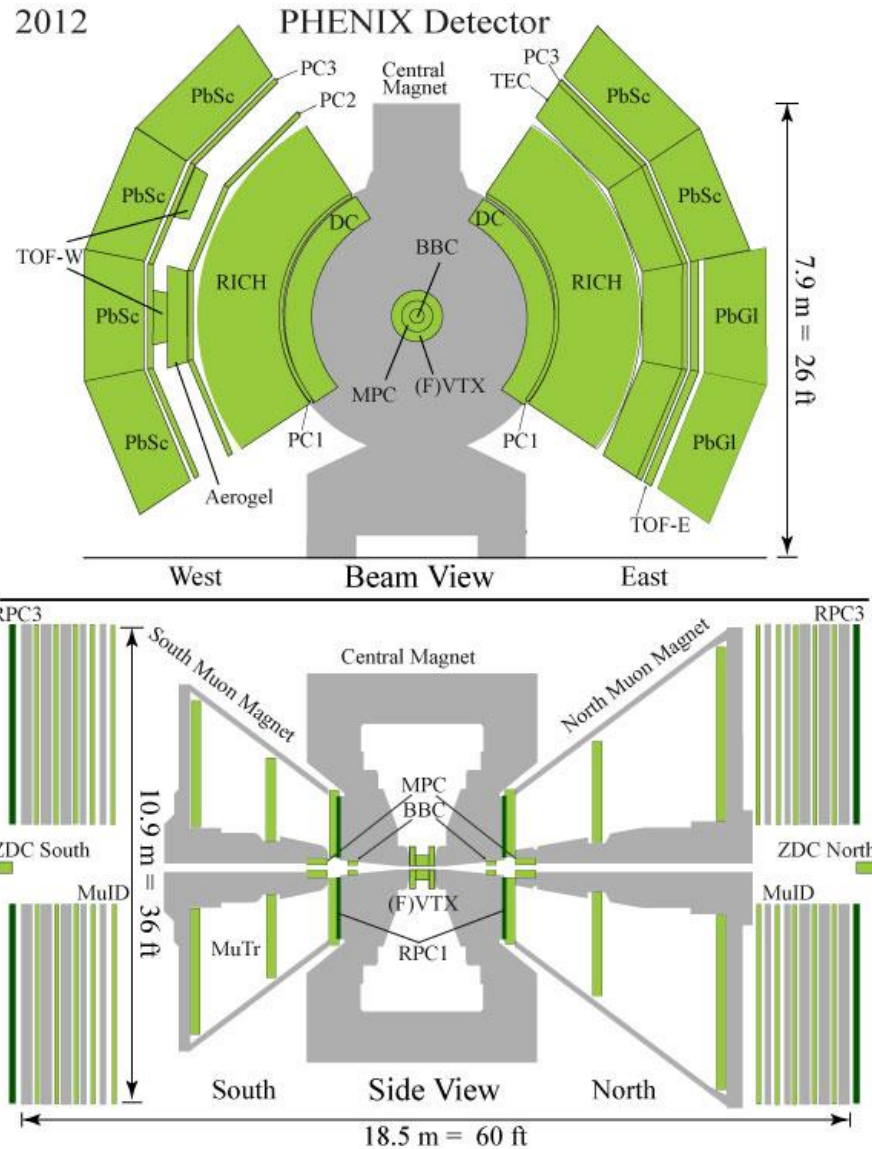
Many competing processes in AA collisions:
cold nuclear matter effects, color screening, initial state effects, regeneration, feed-down...

... need measurements for different energies,
colliding species, quarkonium states.



Mocsy & Petreczky
PRL. 99, 211602 (2007)

The PHENIX Experiment



Quarkonium states are measured via di-lepton decays

Central Arms (electrons)

$$|\eta| < 0.35 \quad \Delta\phi = 2 \times \pi/2$$

$$P > 0.2 \text{ GeV}$$

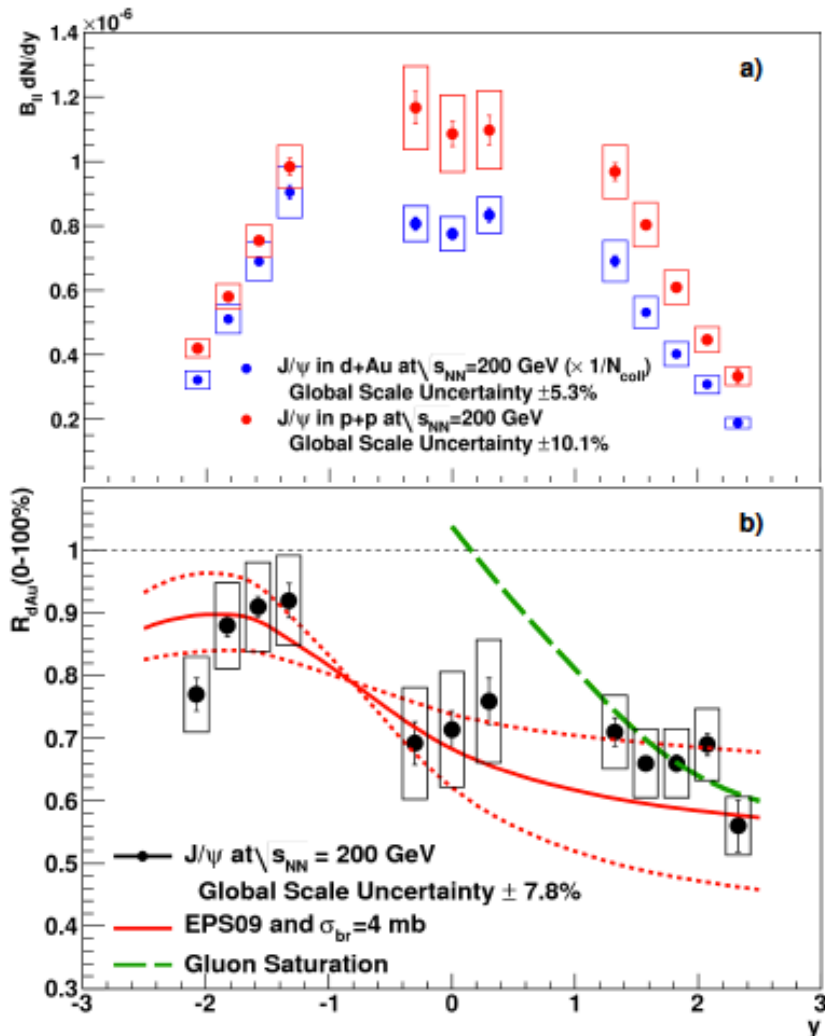
Muon Arms

$$1.2 < |\eta| < 2.2 \quad \Delta\phi = 2\pi$$

$$P > 2 \text{ GeV}$$

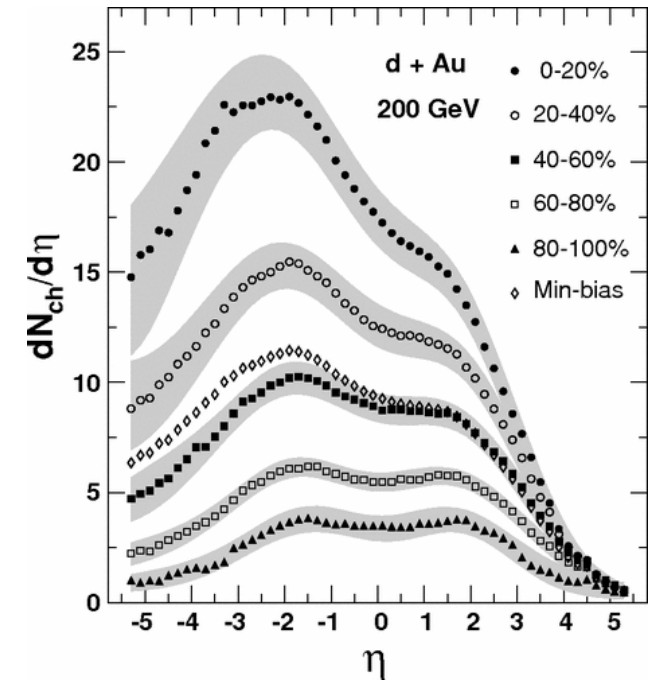
d+Au collisions: a good way to study CNM

PRL 107, 142301 (2011)



Rapidity-dependent R_{dAu} :
Forward (deuteron going)
rapidity shows more
suppression than central
and backward (Au going)
rapidity.

PHOBOS PRC 72, 031901(R)

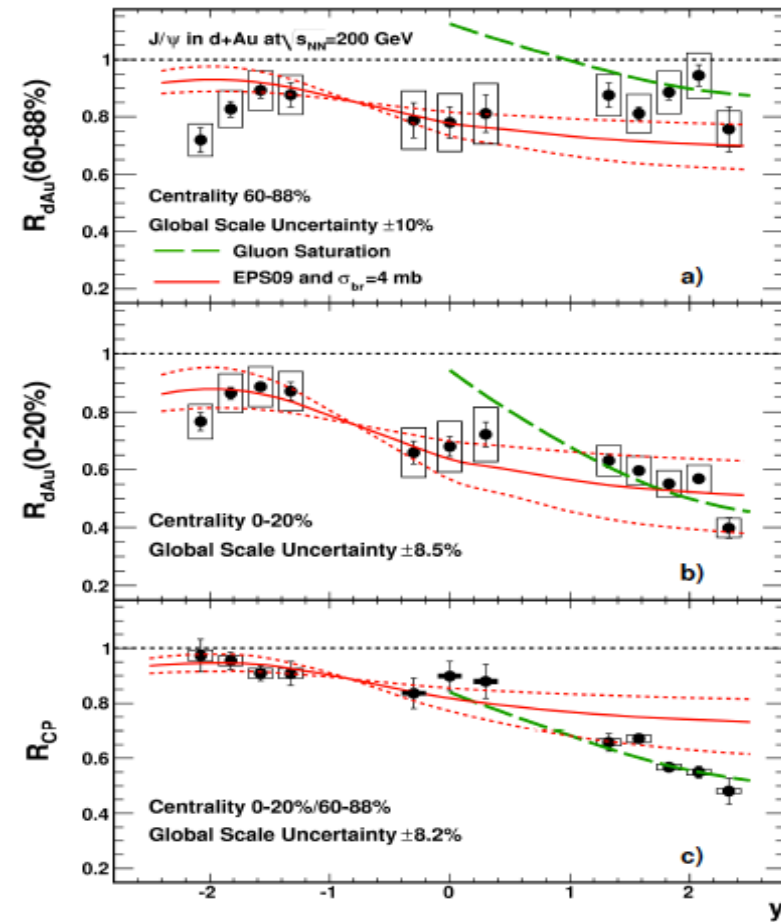


Many possible explanations, including nuclear
breakup, gluon shadowing, etc...

A reasonable agreement with EPS09 nPDF + $\sigma_{br} = 4$ mb

d+Au collisions: a good way to study CNM (2)

PRL 107, 142301 (2011)

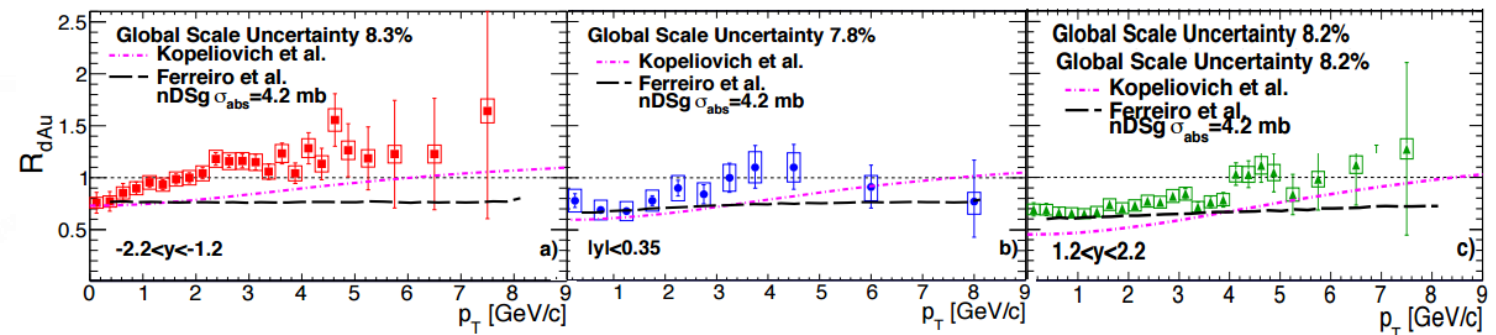


Centrality dependence: agreement with EPS09 nPDF + $\sigma_{br} = 4$ mb only for central collisions but not for peripheral. Gluon saturation explains centrality dependence for forward rapidity.

R_{dAu} rises up to 5 GeV/c; largest disagreement with theories at backward rapidity.

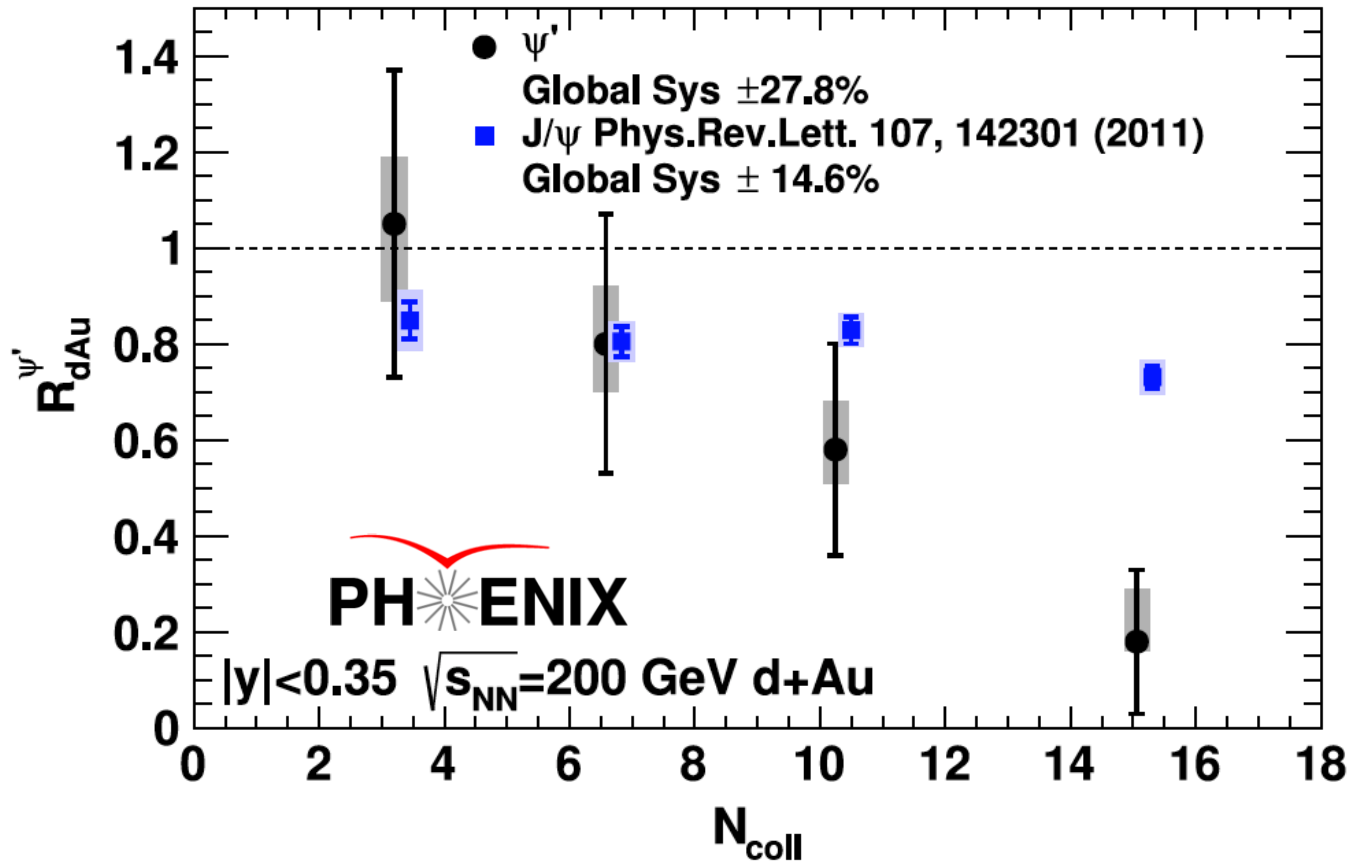
Shadowing + σ_{br} does not match the trend.

The model by Kopeliovich et al. includes Cronin and σ_{br} qualitatively matches the shape



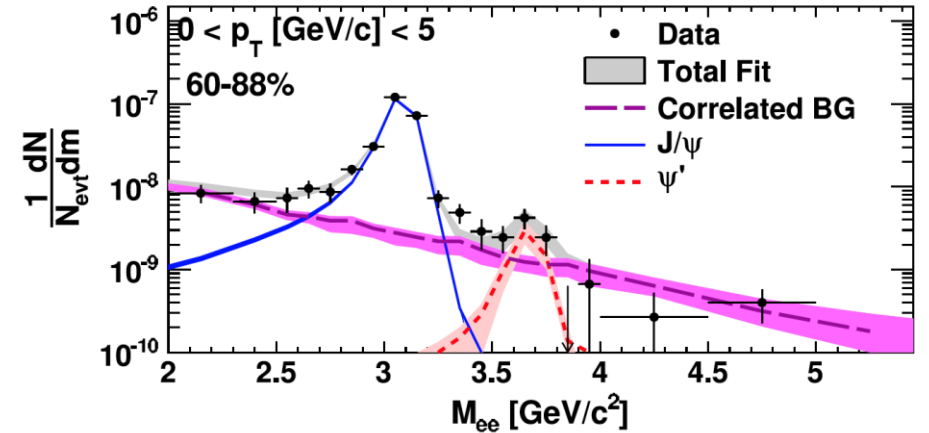
ψ' in d+Au at mid-rapidity

PRL 111, 202301 (2013)

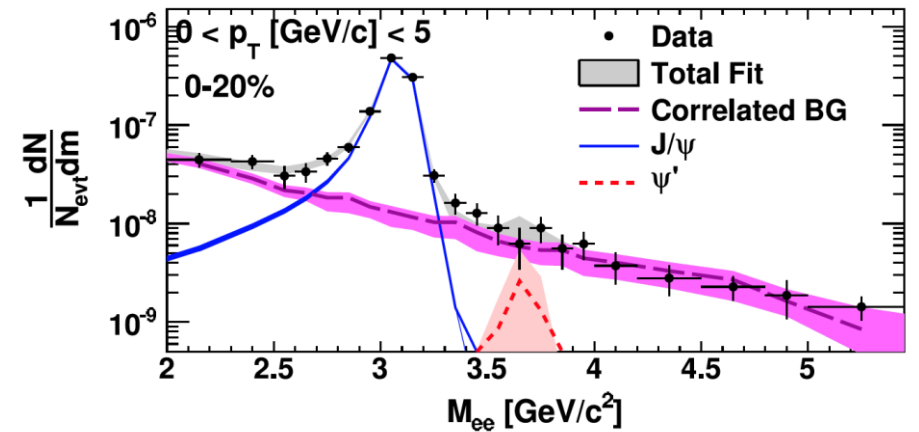


Unexpectedly, ψ' is ~ 3 times more suppressed in most central collisions than J/ ψ . Very different trend with N_{coll} .

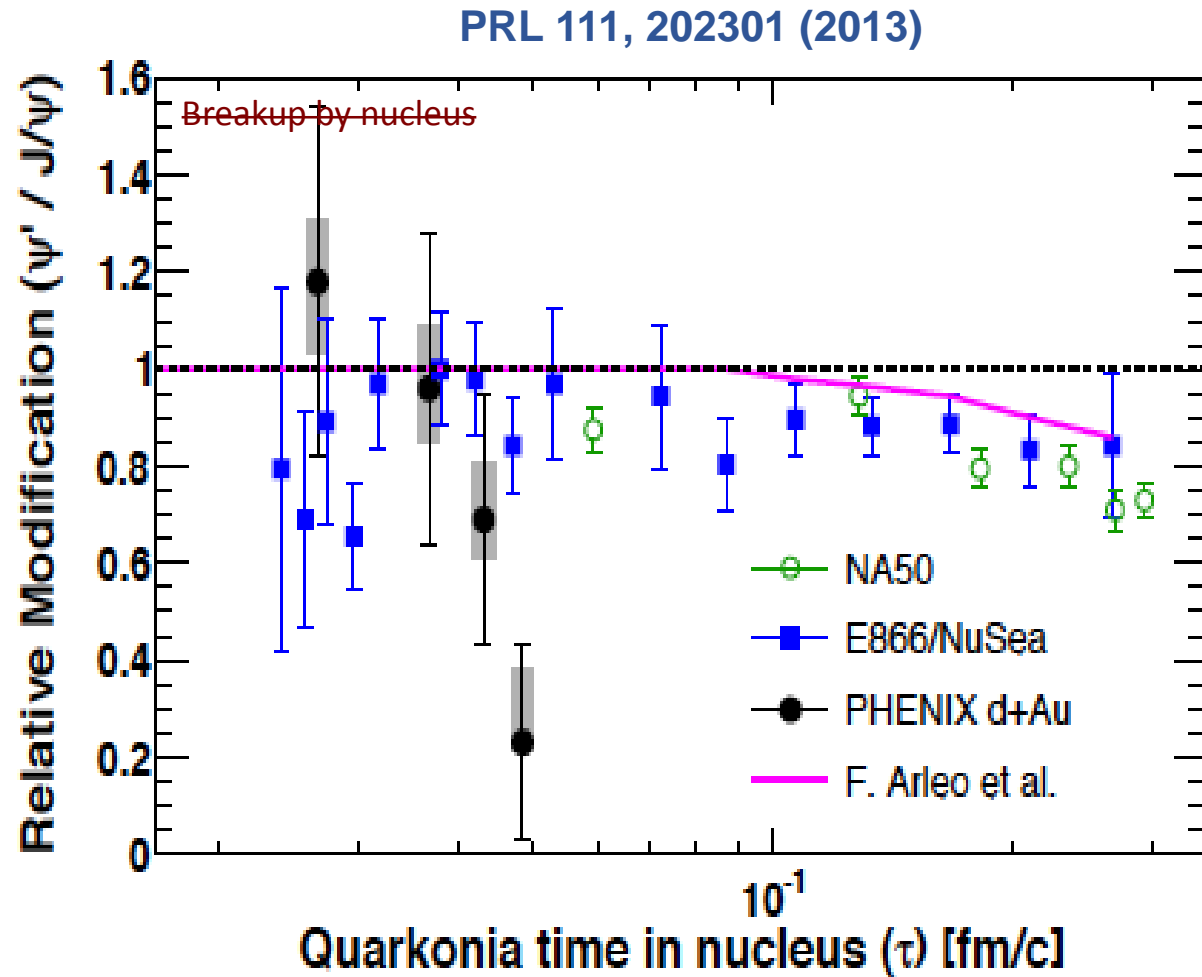
Peripheral d+Au



Central d+Au

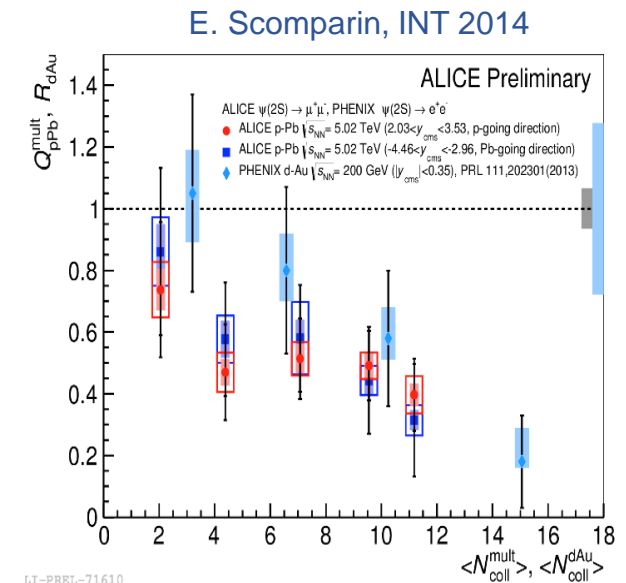


Nuclear crossing time in d+Au



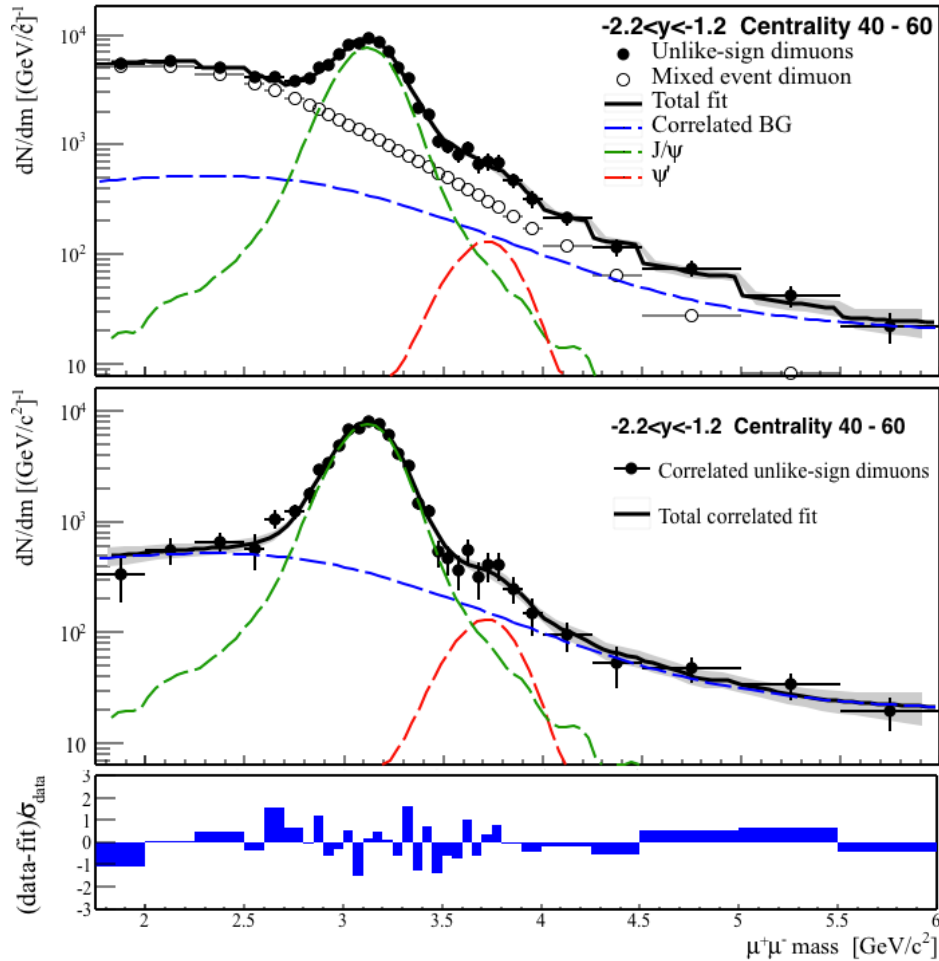
Universal trend with $dN_{ch}/d\eta$ for several systems, up to 200 GeV.
Time spent in nucleus (breakup) does not hold as explanation for PHENIX data.

Similar trend at LHC:



LI-PREL-71610

ψ' in Cu+Au (work in progress)



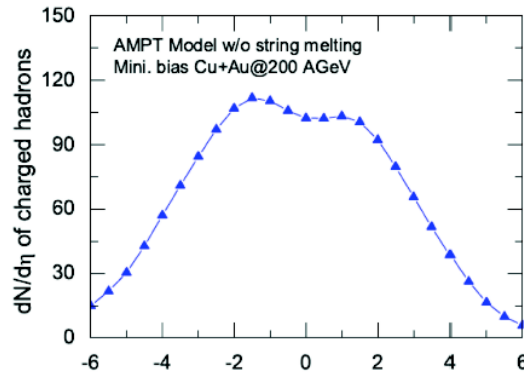
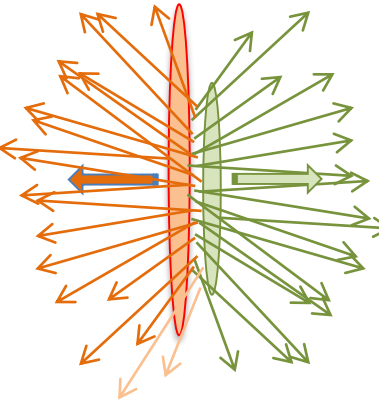
PHENIX is working on extracting ψ' yields in Cu+Au collisions at forward/backward rapidity.

The analysis involves the new Forward Vertex Detector (FVTX).

Still work in progress; ψ' peak can be seen in peripheral collisions.

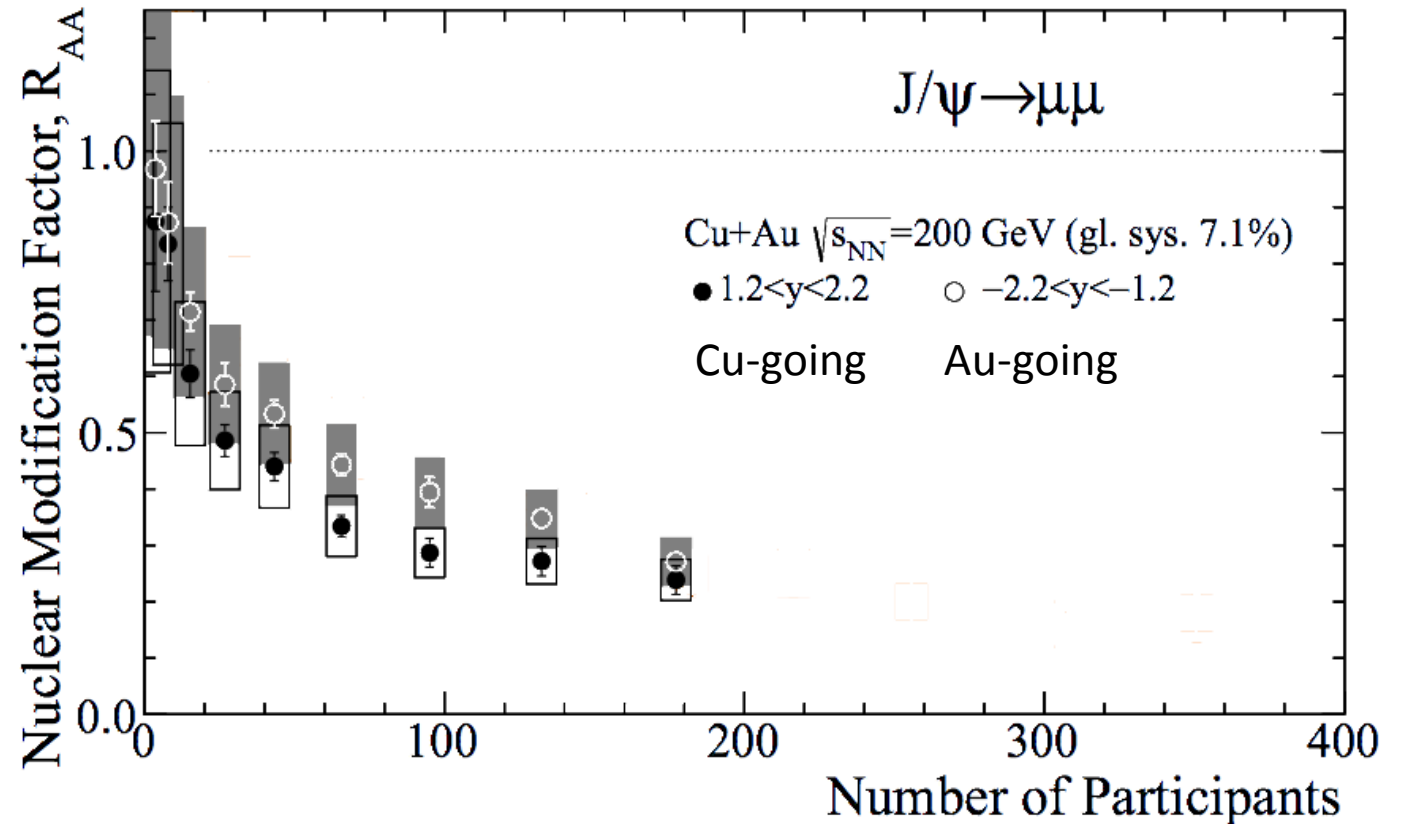
J/ψ in Cu+Au: is R_{AA} still asymmetric?

arXiv:1404.1873



Interplay between “hot” and cold nuclear matter effects.

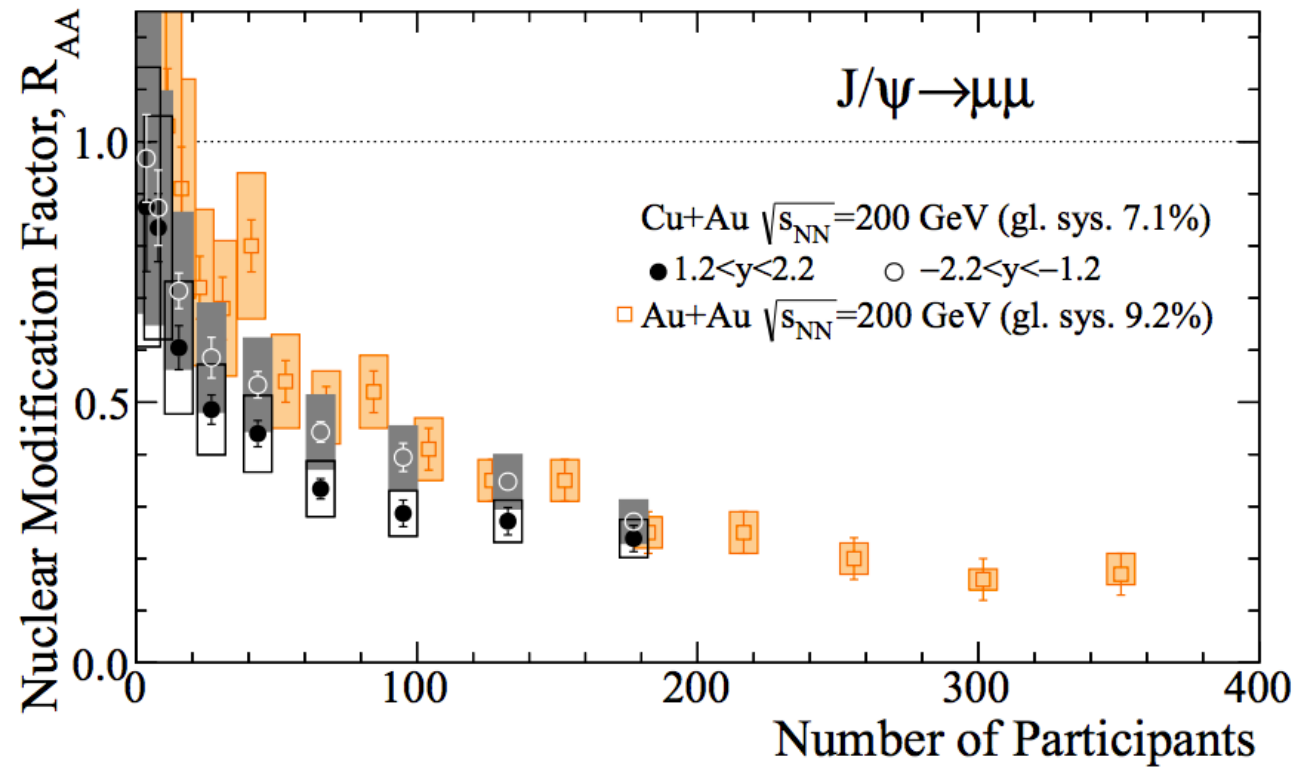
- 1) Asymmetric CNM effects.
- 2) HNM effects possibly asymmetric.



Higher suppression in region of lower particle density (forward rapidity), similar to d+Au collisions.
Debye screening would go in other direction.

J/ψ in Cu+Au compared to Au+Au

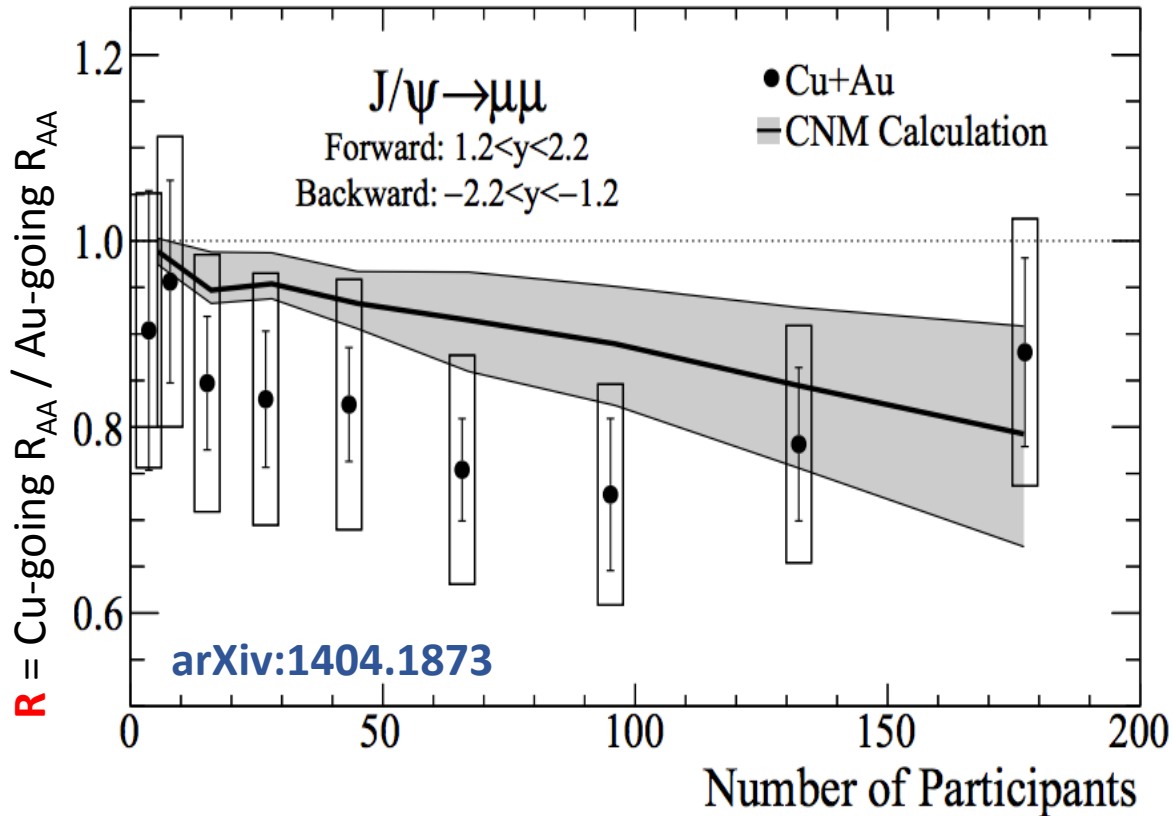
arXiv:1404.1873



Similar or stronger (?) suppression in peripheral Cu+Au, but becomes equal in central collisions.

J/ψ in Cu+Au: Cu-going/Au-going ratio

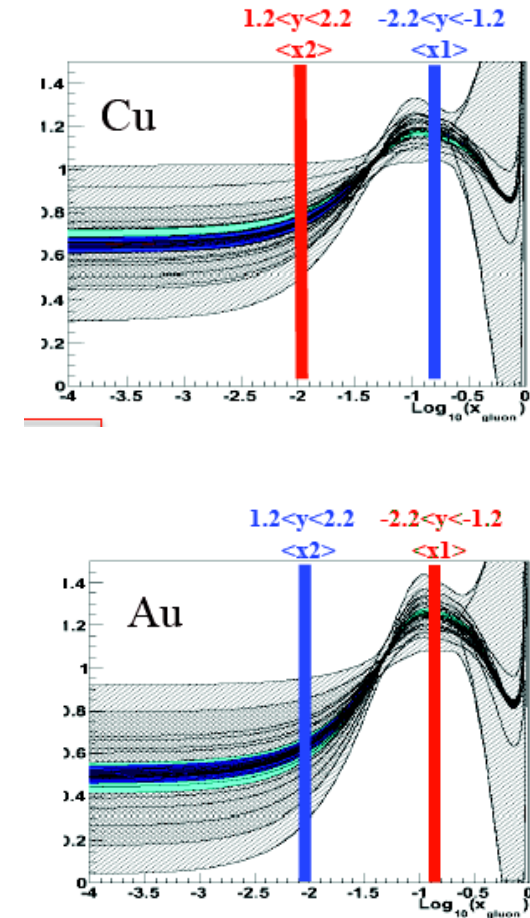
CNM = EPS09 + 4mb breakup (Phys. Rev. C84, 044911, 2011)



Observed **R** decreases with centrality.

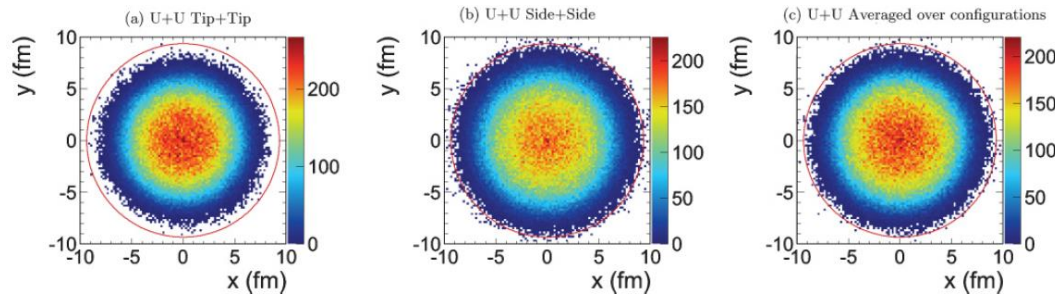
Au-going direction :
low-x partons in Cu nucleus and high-x partons in Au nucleus.

Cu-going direction:
low-x partons in Au nucleus and high-x partons in the Cu nucleus.

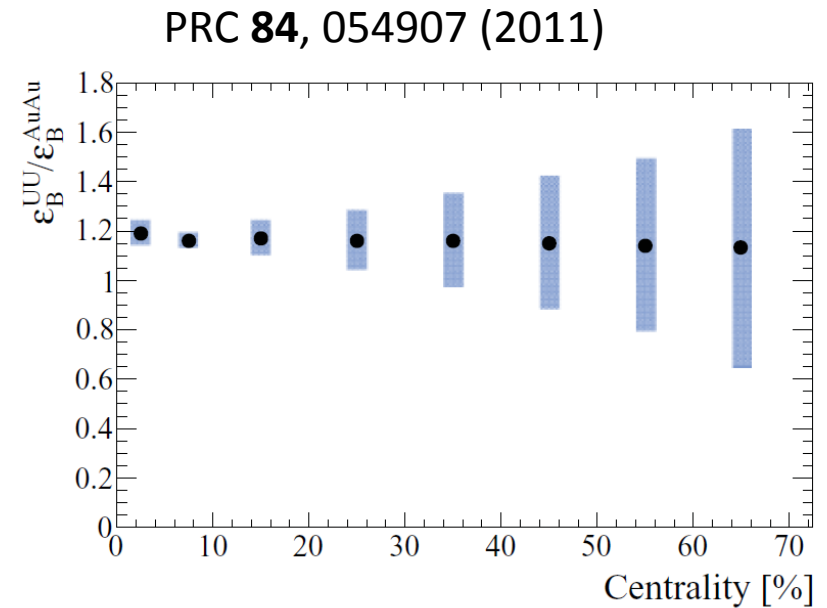


U+U Collisions

Collisions of deformed U nuclei produce wide variation in energy density within the same colliding system.

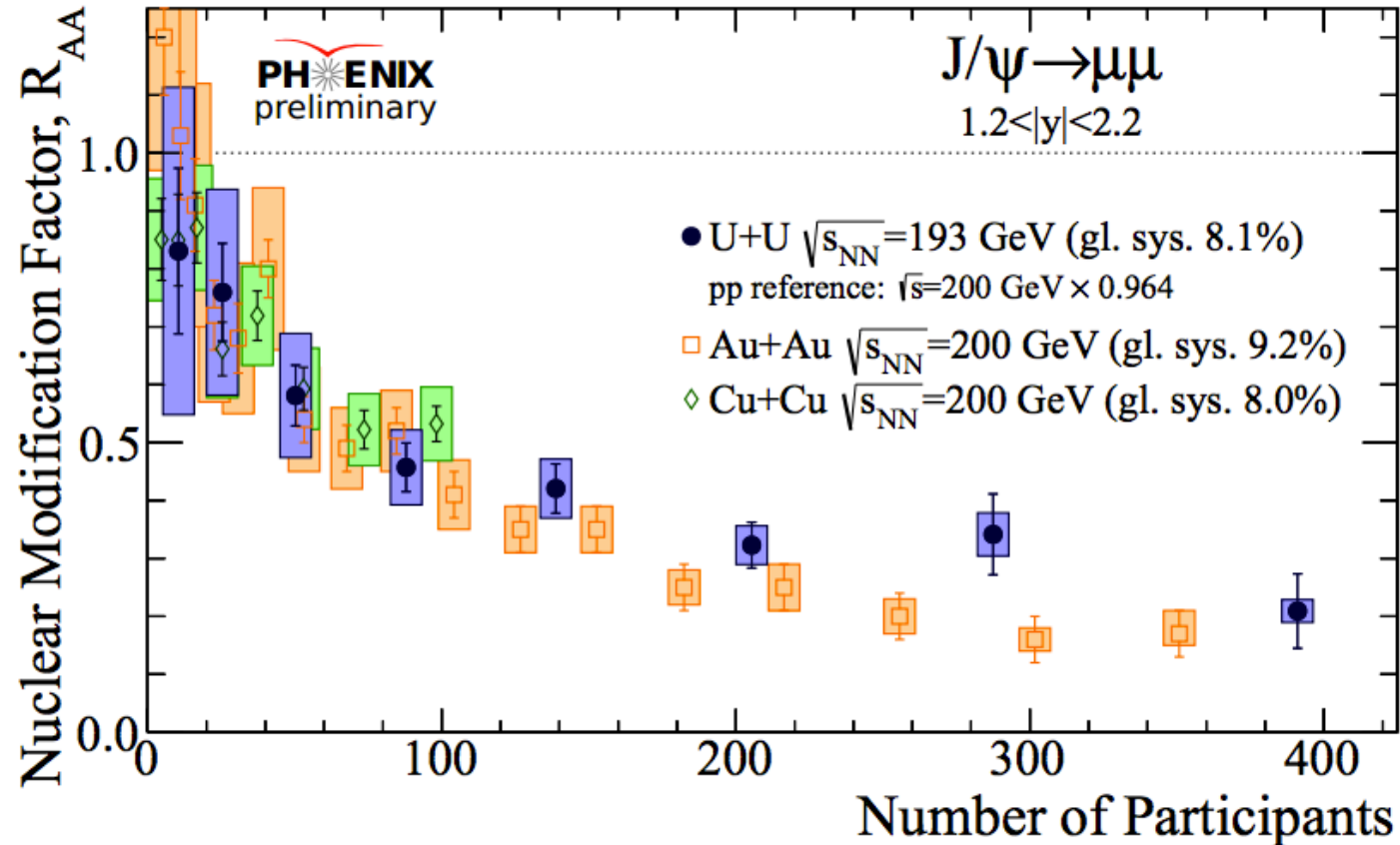


MC studies show [e.g. PRC **76**, 051902 (2007)] a possibility of selecting experimentally tip-tip collisions (high multiplicity, low flow). In tip-tip collisions T/T_c could be reach above 2 [PRC **84**, 054907 (2011)] at which $Y(1S)$ could dissociate.



Averaged over orientation energy density is 15-20% higher than in Au+Au

J/ψ in U+U



Qualitatively similar suppression from Cu+Cu to U+U.

Somewhat weaker suppression in central U+U collisions?
Higher coalescence?

Conclusions and Outlook

Significant suppression of J/ψ in d-Au.

In Cu+Au collision, the Cu going side is more suppressed than Au going side due to CNM effects, sensitive to the low x of the Au nuclei.

The magnitude and trend of $\psi(2s)$ suppression in nuclear collisions is quite different from J/ψ . Nuclear crossing time does not explain the data.

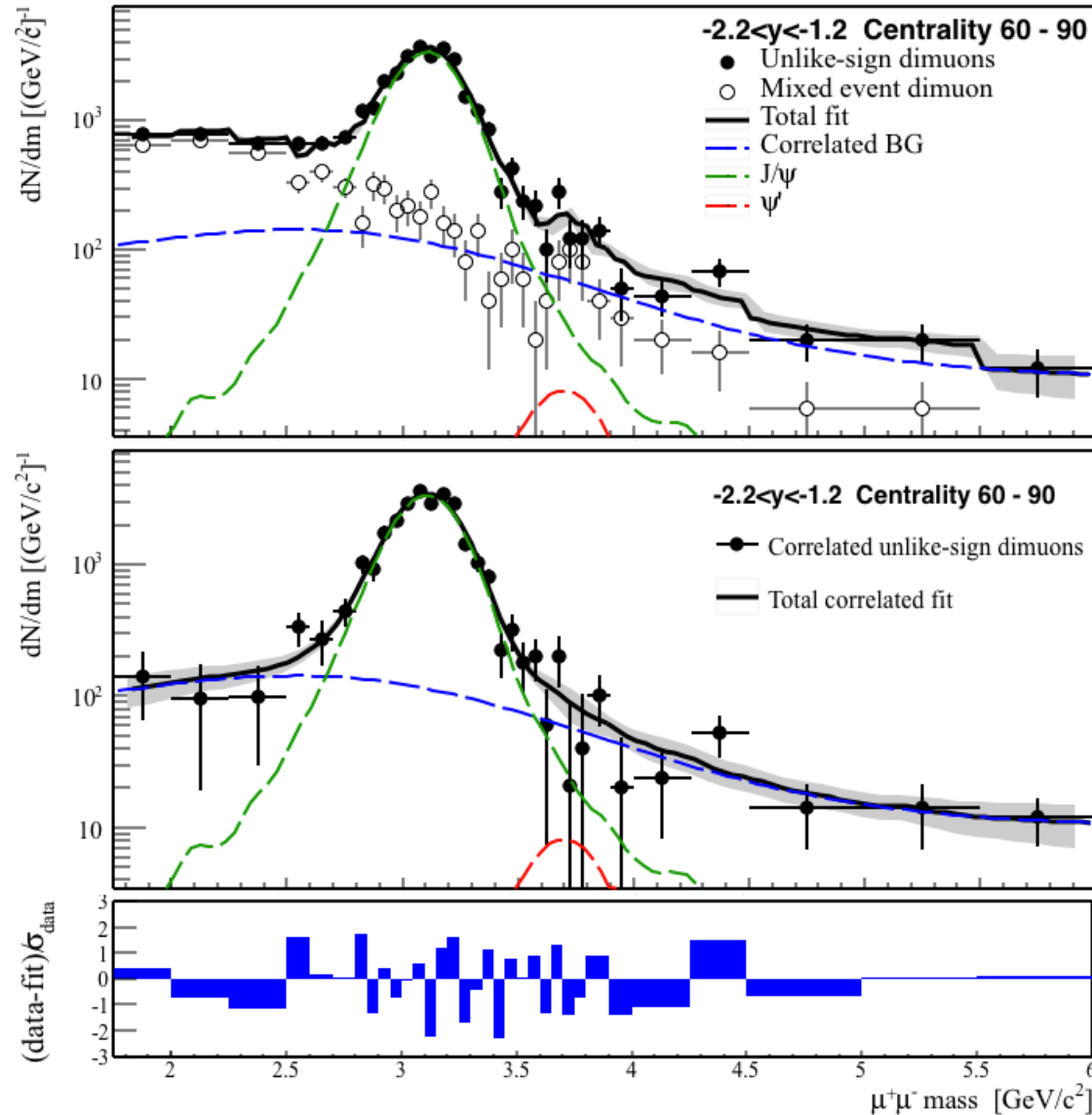
$J/\psi R_{AA}$ is qualitatively consistent between different colliding systems, from Cu+Cu to U+U. ~20% differences despite expected variations in the CNM and QGP effects.

Recombination is important?

Potentially interesting to try to select tip-tip U+U collisions.

backup slides

ψ' in Cu+Au



$$p_{\text{fit}}/p_{\text{max}} = 0.55$$

$$N. J/\psi \text{ counts} = 1266^{+47}_{-45}$$

$$R_{\psi'/(J/\psi)} = 0.20^{+0.84}_{-0.20} \%$$

$$N. \psi' \text{ counts} = 3^{+14}_{-3}$$

$$m_{\text{smear}} = \left(52^{+12}_{-13} \right) \text{ MeV}/c^2$$

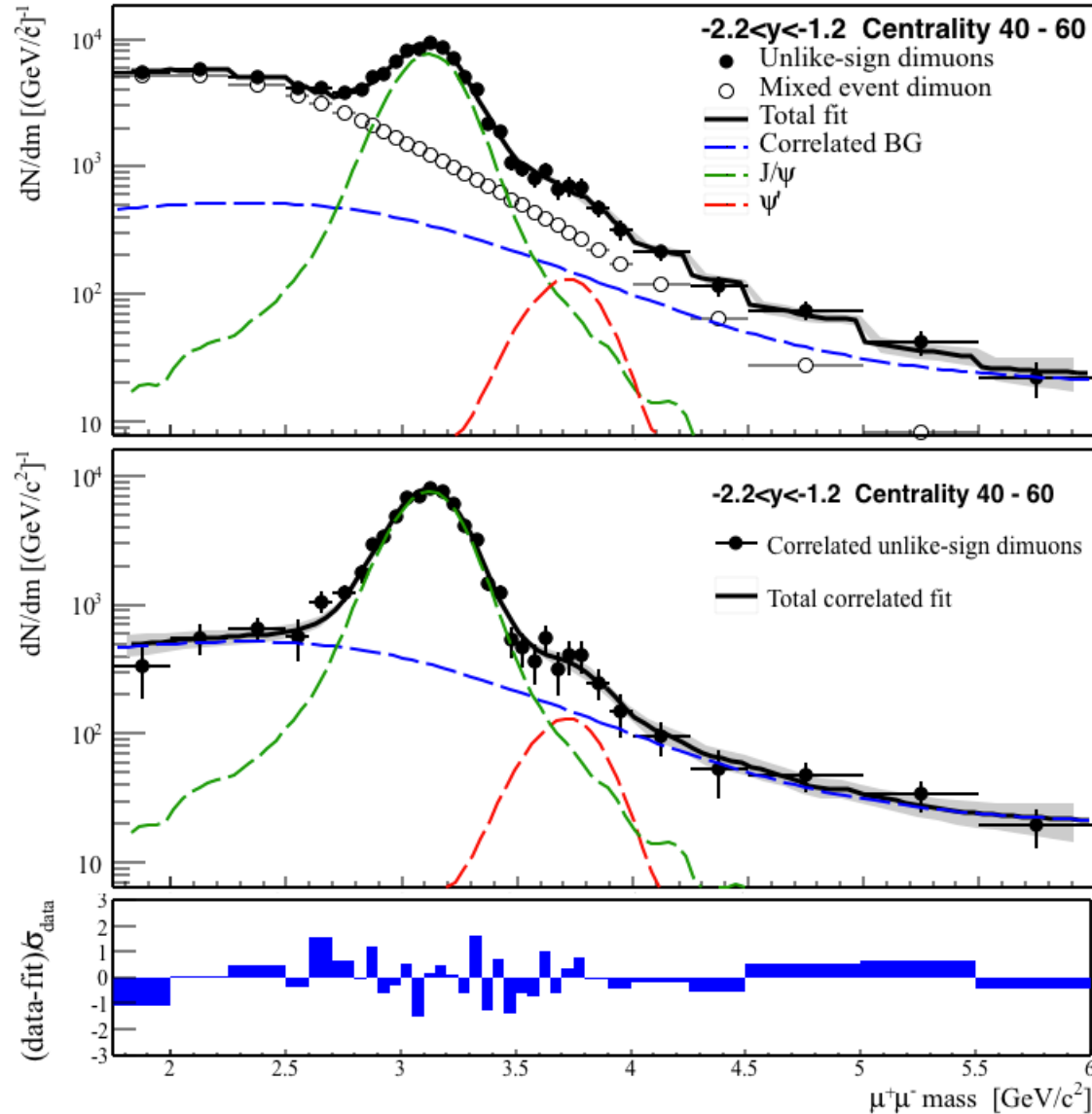
$$\frac{N_{\text{corrBG}}}{N_{J/\psi}} = 0.215^{+0.047}_{-0.044}$$

$$f_{\text{hm}} = 0.040^{+0.019}_{-0.017}$$

$$\lambda_{\text{lm}} = -1.87^{+0.76}_{-0.25}$$

$$\lambda_{\text{hm}} = -0.0^{+0.0}_{-4.0}$$

ψ' in Cu+Au



$$p_{\text{fit}}/p_{\text{max}} = 0.39$$

$$N. J/\psi \text{ counts} = 2898^{+89}_{-84}$$

$$R_{\psi'/(J/\psi)} = 1.41^{+0.72}_{-0.71} \%$$

$$N. \psi' \text{ counts} = 54^{+28}_{-27}$$

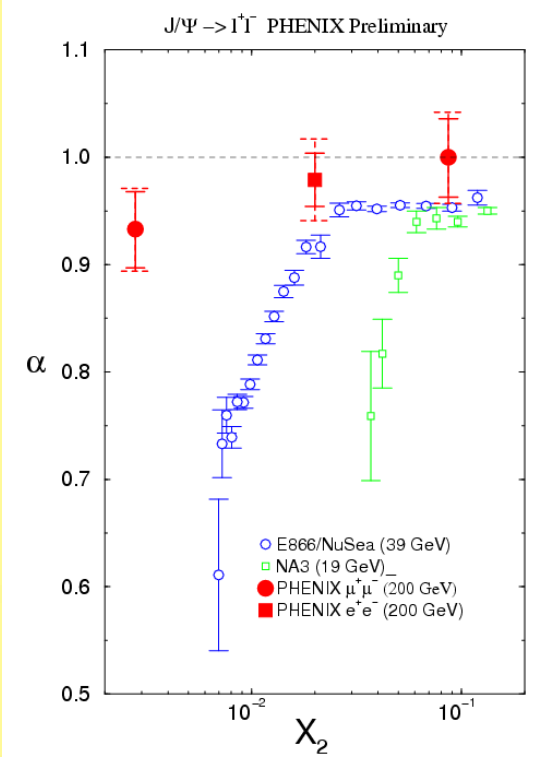
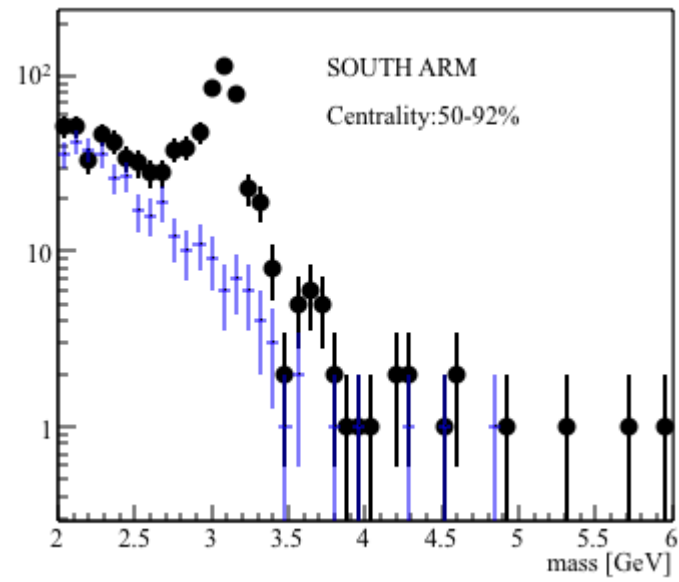
$$m_{\text{smear}} = \left(49^{+10}_{-12} \right) \text{ MeV}/c^2$$

$$\frac{N_{\text{corrBG}}}{N_{J/\psi}} = 0.303^{+0.047}_{-0.046}$$

$$f_{\text{hm}} = 0.024^{+0.038}_{-0.010}$$

$$\lambda_{\text{lm}} = -2.08^{+0.37}_{-0.19}$$

$$\lambda_{\text{hm}} = -0.2^{+0.2}_{-3.2}$$



d+Au

